NASA-CR-202647

Final Technical Report

for

Aeroelastic Stability & Response of Rotating Structures

NASA Grant Number
NAG3-1137

Grant Duration
January 30, 1990 to November 7 1995

Theo G. Keith, Jr.
Distinguished University Professor
&
T.S.R. Reddy
Senior Research Associate

Department of Mechanical, Industrial and Manufacturing Engineering
University of Toledo
Toledo, Ohio 43606

November 1996

Aeroelastic Stability and Response of Rotating Structures

A summary of the work performed under grant NAG3-1137 is presented herein. More details can be found in the cited references. This grant led to the development of aeroelastic analysis methods for predicting flutter and forced response in fans, compressors, and turbines using computational fluid dynamic (CFD) methods.

(A) Analysis of Multi Blade Row Fans, Compressors, and Turbines

In this portion research effort, as a to guide future research, a review of the aeroelastic methods developed at NASA Lewis was undertaken. This review was presented in Ref. A.1. The review indicated that most of the methods developed were for isolated blade rows, and were of limited scope since they were mainly intended to be used for gust response prediction. Therefore, an effort was started to develop a two-dimensional Euler multistage aeroelastic solver. The isolated blade solver developed earlier, Ref. A.2, was used as the basis for this development. The progress made in the development of the multistage aeroelastic code was presented in Refs. A.3-A.5. The resulting code, MSAP2D, can be used for steady, unsteady, and aeroelastic analysis. The code can handle unequal number of blades in the rows, and any number of blade rows. A user's manual was written in order to disseminate the code and provide code access to other researchers, Ref. A.6. During the grant period, a new robust solution algorithm was developed to be used with the Euler solver, Ref. A.7.

In the grant period, user's manuals were also written for the analysis methods and codes developed earlier, the ASTROP2 code, Ref. A.8. and the ECAP2D code, Ref. A.9. The ASTROP2 code is a fast running, desk top aeroelastic analysis code developed under the Advanced Turboprop Project (ATP). It has been revised and updated by the researchers of the present grant. Therefore, a write up of the user's manual for the updated version (version 2.0) was required. The Euler code developed earlier for the isolated blade row, Ref. A.2, did not have a user's manual, thus one was needed.
During the current grant period, a gust response capability was added to MSAP2D code, Ref. A.10. The MSAP2D code can now be used for flutter and forced response of isolated blade rows, and also for multiblade row configurations. Also, during this period, another version of the code was

developed incorporating the new algorithm, and viscous terms, developed in Ref. A.7.

During this period, the investigators also collaborated with NASA Lewis researchers to guide on the flutter of the Pratt & Whitney wide chord fan blade. The existing codes were run for this blade, and findings were reported to the NASA authorities.

(B) Three Dimensional Aeroelastic Analysis Method for Propfans

During this period the researchers of this grant collaborated in developing three-dimensional aeroelastic analysis methods for propfans. Even though, the two-dimensional aeroelastic analysis methods presented in section A, are fast, and give accurate prediction of the flow and aeroelastic characteristics away from the tip, three-dimensional effects can be important in the tip region. With this view, two analysis methods, one based on full potential equation, and the other on Euler equations was developed. Both were calibrated with experimental data available for propfans. This work was reported in Refs. B.1-B.3. A user's manual was also written for the code based on Euler equations, Ref. B.4.

(C) Ducted Fan Aeroelasticity

Usually, the engine of subsonic transport is enclosed in a duct. Analysis methods were developed to include the effect of duct on the flutter behavior of fans, Refs. C.1-C.2. A user's manual was also written for the resulting computer code, Ref. C.3.

Bibliography

A.1. Reddy, T.S.R., Bakhle, M.A., Srivastava, R., Mehmed, O. and Stefko, G.L.:"A Review of Recent Aeroelastic Analysis Methods for Propulsion at NASA Lewis Research Center", NASA TP 3406, 1993.

A.2. Reddy, T.S.R., Bakhle, M.A., Huff, D.H. and Swafford, T.W.:"Flutter Analysis of Supersonic Axial Flow Cascades Using a High Resolution Euler Solver, Part 1: formulation and validation", NASA TM 105798, 1992

A.3. Reddy, T.S.R. and Srivastava, R.:"Unsteady Rotor-Stator interaction Including Aeroelastic Effects", AIAA-93-2237, 29th Joint Propulsion Conf., June 28-30, 1993, Monterey, CA.

A.4. Srivastava, R. and Reddy, T.S.R.:"Forced Response Analysis Using a Multistage Euler Aeroelastic Solver", AIAA-94-0739, 32nd Aerospace Sciences Meeting & Exhibit, January 10-13, 1994, Reno, NV.

A.5. Reddy, T.S.R. and Srivastava, R.:"Analysis of a Rotor-Stator stage using a Two-Dimensional Euler Aeroelastic Solver", AIAA 94-1638, 1994, 35th SDM, April 18-20, Hilton Head, SC.

A.6. Reddy, T.S.R. and Srivastava, R., User's Guide for MSAP2D: A Program for Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of MultiStage Compressors and Turbines, NASA CR 198521, August 1996

A.7. Swafford, T.W., Loe, D.H., Huff, D.L., Huddleston, D.H. and Reddy, T.S.R.:"The Evolution of NPHASE: Euler/Navier-Stokes Computations of Unsteady Two-Dimensional Cascade Flow Fields", AIAA-94-1834,12th Applied Aerodynamics Conference, June 20-22, 1994, Colorado Springs, CO.

A.8. Reddy, T.S.R.:"User's Guide for ECAP2D: An Euler Unsteady Aerodynamic and Aeroelastic Analysis Program for Two Dimensional Oscillating Cascades", Version 1.0, NASA CR 189146, April 1995.

A.9. Reddy, T.S.R. and Lucero, J.L.:"ASTROP2 Users Manual: A Program for Aeroelastic Stability Analysis of Propfans, Version 2.0", NASA TM 107195, March 1996.

A.10. Reddy, T.S.R. and Srivastava, R.:"Gust and Structural Response Analysis of a 2D Cascade Using an Euler Aeroelastic Solver", AIAA-96-1492,1996, 37th SDM, April 15-17, Salt Lake City, UT.

B.1. Bakhle, M.A. and Reddy, T.S.R.:"Unsteady Aerodynamics and Flutter of Propfans using a 3D Full Potential Solver", AIAA Paper 93-1633, 34th SDM, April 19-22, La Jolla, CA.

B.2. Srivastava, R., Reddy, T.S.R. and Mehmed, O.:"Flutter Analysis of Propfans Using a Three Dimensional Euler Solver", AIAA 94-1549,1994, 35th SDM, April 18-20, Hilton Head, SC.

B.3. Srivastava, R., Reddy, T.S.R. and Mehmed, O.:"Aeroelastic Analysis of Advanced Propellers Using an Efficient Euler Solver", AIAA-92-0488, 30th Aerospace Sciences Meeting, Reno, Jan. 6-9, 1992.

B.4. Srivastava, R. and Reddy, T.S.R.:"PROP3D: A Program for 3D Euler Unsteady Aerodynamic and Aeroelastic (Flutter and Forced Response) Analysis of Propellers", Version 1.0, NASA CR 198471, April 1996.

C.1. Srivastava, R. and Reddy, T.S.R.:"Aeroelastic Analysis of Ducted Rotors", presented at the International Symposium on Computational Fluid Dynamics in Aeropropulsion, 12-17, November 1995, San Francisco, CA.

C.2. Srivastava, R., Reddy, T.S.R. and Stefko, G.L.:"A Numerical Aeroelastic Stability Analysis of a Ducted-Fan Configuration", AIAA 96-2671, 32nd Joint Propulsion Conference, July 1-3, 1996, Lake Buena Vista, FL.

C.3. Srivastava, R. and Reddy, T.S.R.:"DuctE3D: A Program for 3D Euler Unsteady Aerodynamic and Aeroelastic Analysis of Ducted Fans", Version 1.0, NASA CR in print.